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A. Balsamo, D. Corona, A.Piccato, G.B. Picotto, A. Egidi

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I.N.RI.M. TECHNICAL REPORT

Abstract

This technical report describes the calibration of a ball bearing ring segment. INRIM designed the ring segment to be representative of bearing rings Ø > 1 m and MG Marposs S.p.a. (Turin, Italy) manufactured the workpiece. The calibration has been performed with the coordinate measuring machine CMM/ST001 at INRIM.
The present work is related to the deliverable 2.2.3 of Drive Train Poject (ENG56).

Questo rapporto tecnico descrive la taratura di un segmento di anello di un cuscinetto a sfere. L'INRIM ha progettato il segmento di anello che è stato quindi prodotto dalla MG Marposs S.p.a. di Torino. La taratura è stata eseguita con la macchina a coordinate CMM/ST001 dell'INRIM.
Questo lavoro si colloca all'interno del Progetto DriveTrian (ENG56) come deliverable 2.2.3.

1. MEASURAND, MEASUREMENT PROCEDURE AND CONDITIONS

1.1 Measurands

The ring segment embodies two nominally coaxial features: a cylinder and a torus. Both the cylinder and the torus are highly partial features, which poses a challenge for the calibration [1] The torus is partial along its ring and its tube, and the cylinder has an aperture of roughly 30° for a diameter of about 1 m. The measurands to calibrate are defined in terms of intrinsic and location features, according to the model for geometrical specification and verification [2] and they are:

- Intrinsic parameters – Radius of cylinder, radius of the ring (torus) and radius of the tube (torus)
- Location parameters (axes) - the coaxiality by torus and cylinder (location), the angles by the axes of torus and cylinder in the radial and tangential planes (orientation);

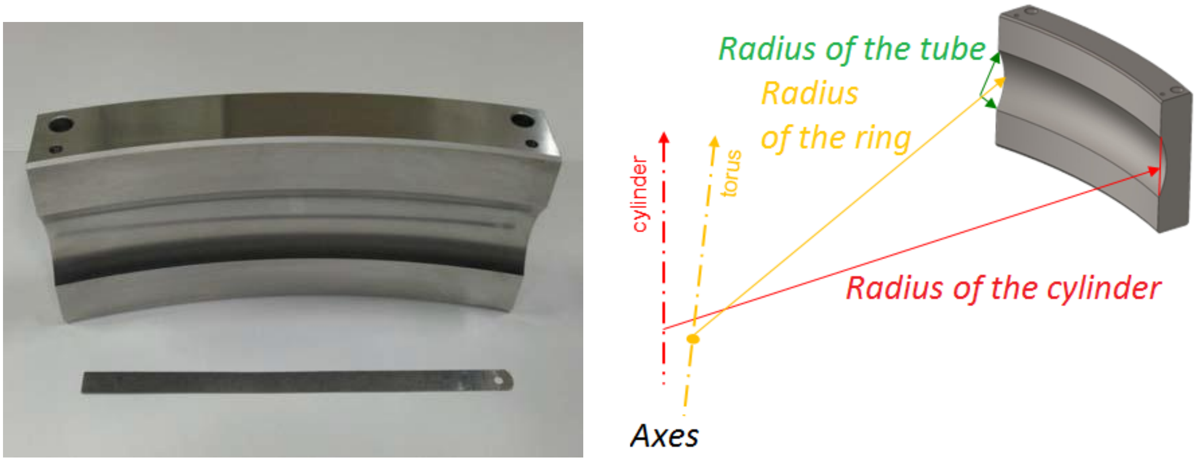
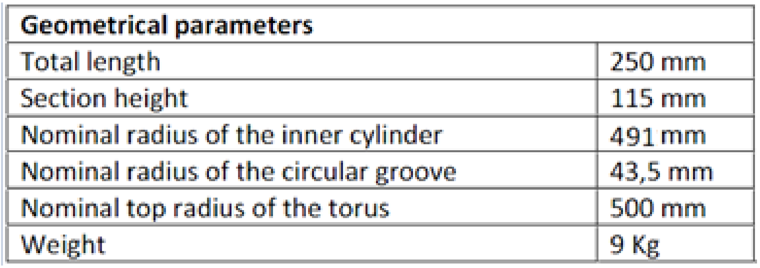


Figure 1: Ring segment photo (left), Sketch of intrinsic and local parameters (right).

The nominal parameters of the ring segment are summarised in the following table and Fig.2:



Geometrical parameters	
Total length	250 mm
Section height	115 mm
Nominal radius of the inner cylinder	491 mm
Nominal radius of the circular groove	43,5 mm
Nominal top radius of the torus	500 mm
Weight	9 Kg

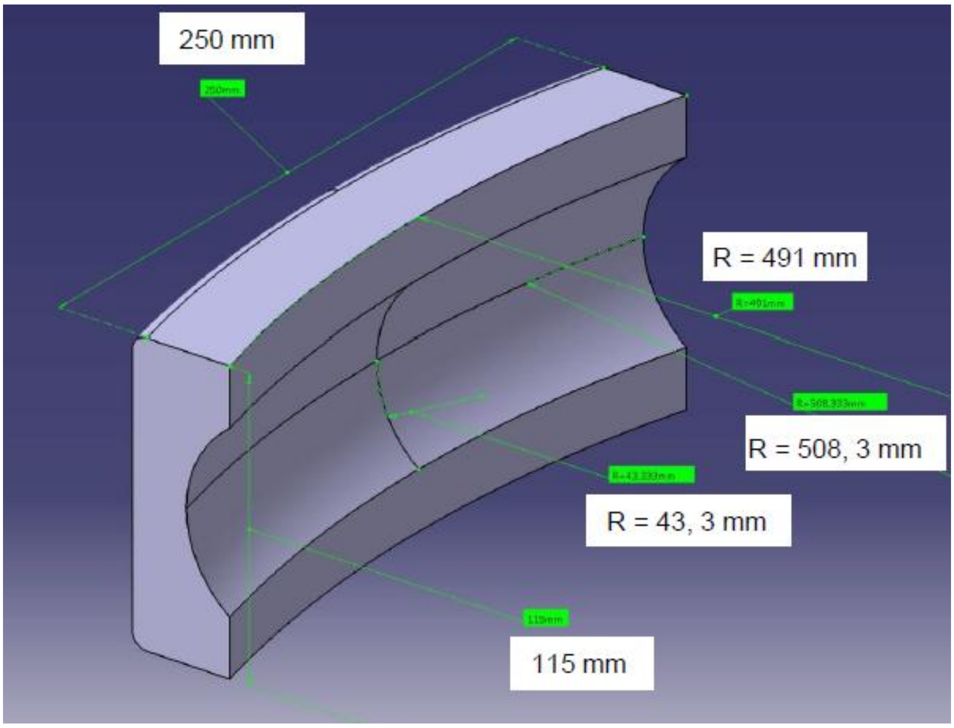


Figure 2: ring segment representative of bearing rings Ø > 1 m

1.2 Procedure

The calibration has been performed with the coordinate measuring machine CMM/ST001, with the ring segment mounted on the workpiece table and a configuration of the stylus system with two stylus: one stylus in horizontal position and one stylus in vertical position. See Fig. 3 and Fig 4 for the set up.

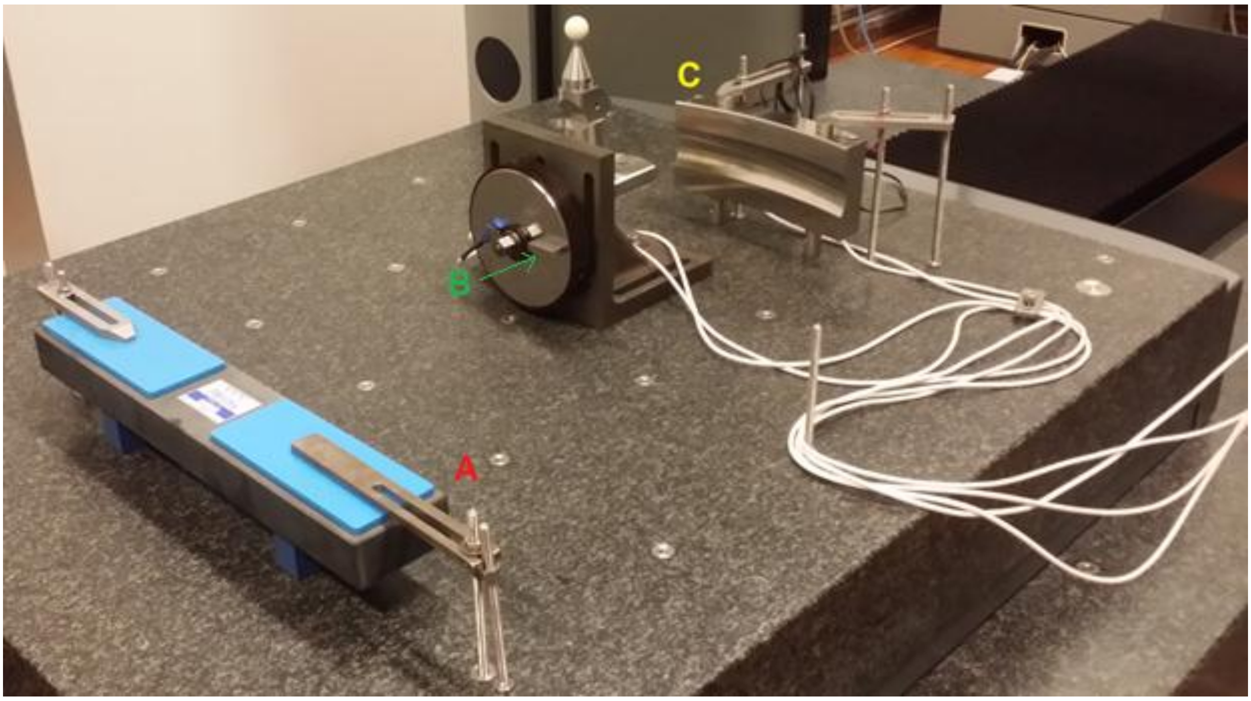


Figure 3: Set up - A: straightness standard; B: short gauge block wrung on a platen; C: ring segment

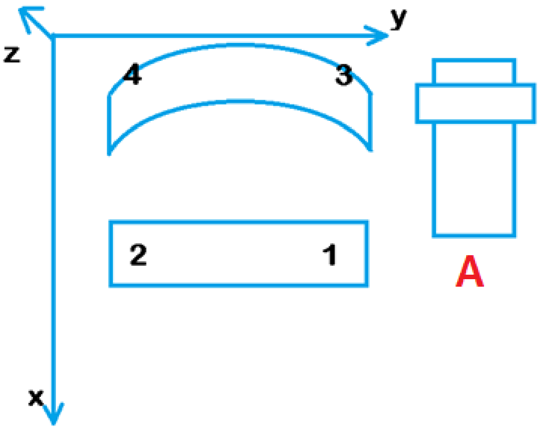


Figure 4: Thermometers displacement (1,2,3 and 4); A: sketch of CMM (machine axes: blue);

Traceability of CMM measurements is underpinned by suitable standards (Fig. 5). Traceability along tangential direction and along radial direction is obtained by means of two gauge blocks, whereas a straightness standard is used to correct the straightness error of the relevant portion of the CMM axis the ring sector is aligned to (Fig. 2).

The calibration is done as follow:
The distance of the two reference pin seats of the standard are calibrated with a CMM by comparison with the calibrated 250 mm gauge block CEJ 750004. This provides traceability in the tangential direction of the standard (precalibration). In subsequent measurements, this distance is measured again, and the coordinates along that direction of measured points are stretched so as to achieve the calibrated value (Fig. 5). This also correct for thermal expansion in that direction.
The calibrated straight edge s/n 13.110 is also measured, to correct for the CMM straightness.
All remaining measurements are then taken, with the addition of the calibrated 160 mm gauge block (set s/n 415.1030 – 30410) which provides traceability along the radial direction. The resulting proportional correction is then propagated to all point coordinates in that direction. The fact that the measured features are highly partial amplifies the CMM errors, specifically the scale error in the radial direction and the straightness error along the tangential direction. These are recovered by comparison with the short gauge block and with the straight edge.

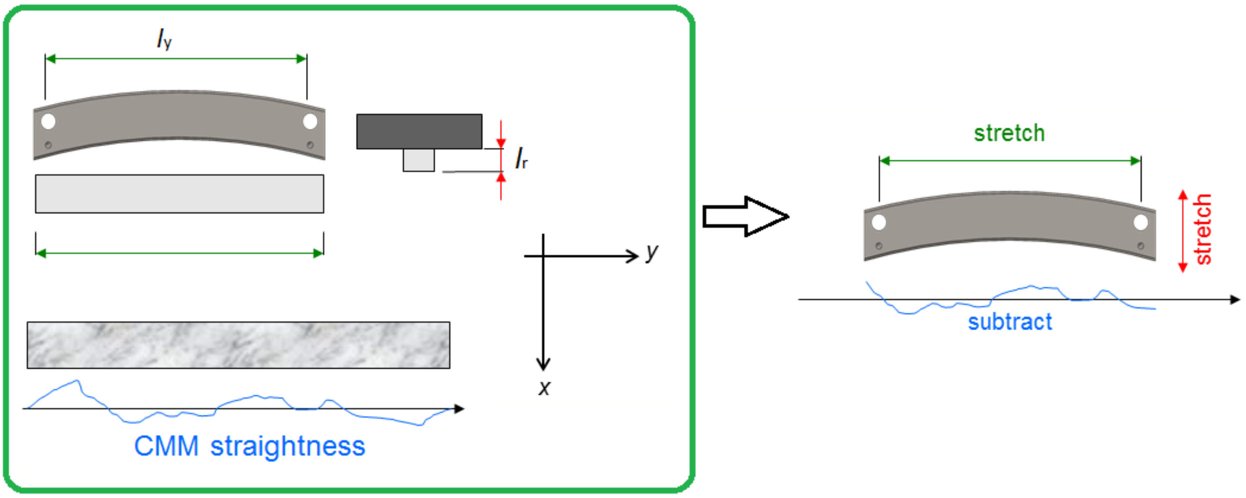


Figure 5: scheme of traceability chain and applied corrections

To minimise the effects of the CMM geometry errors, the calibrated gauge blocks used are aligned parallel and positioned as close as possible to the features under precalibration (Fig. 2). This way the effects of the CMM geometry errors are second order and neglected.

The deviation of the mean temperatures of the ring segment and of the calibrated gauge blocks from the standard reference temperature (20 °C [3]) is relevant to the precalibration and is compensated for. On the contrary, it is not to the actual calibration as the scale factors applied to all sampled points already include and compensate for thermal expansion effects.

1.3 Environmental condition

The ring segment and gauge blocks temperatures varied during the measurement as shown in the following table. The value of the thermal expansion coefficient (CTE) of the ring segment was assumed at (11.5 ± 2.5) × 10^{-6} K^{-1}.

Long gauge block temperature	T_i / °C	T_c / °C	T_f / °C	ΔT / K	ΔT_{20} / K
T_1	19.867	19.871	19.883	-0.016	-0.188
T_2	19.730	19.758	19.765	-0.034	
Ring segment temperature	**T_i / °C**	**T_c / °C**	**T_f / K°C**	**ΔT / K**	**ΔT_{20} / K**
T_3	19.695	19.706	19.715	-0.019	-0.176
T_4	19.920	19.946	19.965	-0.046	

2. MEASUREMENT RESULTS AND ASSOCIATED UNCERTAINTIES

2.1 Results

The calibration values and their uncertainties are reported in the tables below.

		Repetitions 1	2	3	Mean values	Uncertainty *U*
	unit	mm	mm	mm	mm	mm
Cylinder	Radius	491.201 48	491.190 88	491.194 52	491.195 63	0.006 59
Torus	Radius of the ring	455.829 62	455.820 69	455.824 64	455.824 98	0.053 44
	Radius of the tube	44.080 28	44.080 30	44.080 06	44.080 21	0.001 63
	unit	µrad	µrad	µrad	µrad	µrad
	Angle of inclination of the torus axis on the plane xz	444.396	446.054	446.141	445.530	21.729
	Angle of inclination of the torus axis on the plane yz	-74.927	-73.915	-73.915	-74.252	4.778

Furter results	Cylinder mean Form	0.009 81 mm
	Torus mean Form	0.005 04 mm

2.2 Uncertainty

The uncertainty of measurement is summarised in the following tables.

Precalibration	*input uncertainty*		*Sensitivity*		*Standard component*
	$u(x_i)$		c_i		$u_i(y)$ / µm
Resolution	0,029	µm	1,414		0,041
Gauge block calibration	0,025	µm	1		0,025
Gauge block temperature	0,023	K	0,184	µm/K	0,004
Gauge block CDT	0,577	ppm/K	-0,003	K m	-0,002
Workpiece temperature	0,023	K	0,168	µm/K	0,004
Workpiece CDT	1,443	ppm/K	-0,003	K m	-0,004
Probe anisotropy	0,033	µm	1		0,033
				$u(y)$	**0,059**
		(*k*=2)		*U*	0,117

Cylinder radius	*input uncertainty*	*Sensitivity*	*Standard component*
	$u(x_i)$ / µm	c_i	$u_i(y)$ / µm
Stylus tip radius	0,212	1	0,212
Noise of the probing system	0,100	12,543	1,254
Probing system anisotropy	0,033	33,665	1,111
Global scale factor (including traceability), along x	0,059	33,665	1,973
Global scale factor (including traceability), along y	0,128	4,420	0,564
Straightedge	0,155	12,543	1,941
		$u(y)$	**3,291**
	(*k*=2)	*U*	6,583

Ring radius (torus)	*input uncertainty*	*Sensitivity*	*Standard component*
	$u(x_i)$ / µm	c_i	$u_i(y)$ / µm
Stylus tip radius	0,212	1	0,212
Noise of the probing system	0,734	35,476	26,041
Probing system anisotropy	0,033	33,665	1,111
Global scale factor (including traceability), along x	0,059	33,665	1,973
Global scale factor (including traceability), along y	0,128	4,101	0,523
Straightedge	0,155	35,476	5,491
		$u(y)$	**26,715**
	(*k*=2)	*U*	53,431

Tube radius (torus)	input uncertainty $u(x_i)$ / µm		Sensitivity c_i		Standard component $u_i(y)$ / µm
Stylus tip radius	0,212	µm	1		0,212
Noise of the probing system	0,045	µm	6,911		0,309
Probing system anisotropy	0,071	µm	7,464		0,528
Global scale factor (including traceability), along x	0,059	µm	7,464		0,438
Uncorrected bias in z	-0,209	K	0,946	µm/K	-0,198
Workpiece temperature	0,023	K	0,946	µm/K	0,022
Workpiece CTE	1,443	ppm/K	-0,017	K m	-0,025
Global scale factor, along z	0,100		1		0,100
				$u(y)$	**0,813**
	(k=2)			U	1,626

Angle of inclination of the torus axis on the plane xz	input uncertainty $u(x_i)$		Sensitivity c_i		Standard component $u_i(y)$ / µrad
Stylus tip radius	0.707	µm	0		0
Noise of the probing system	0.112	µm	78.997	1/m	8.864
Probing system anisotropy	0.071	µm	63.961		4.523
Global scale factor (including traceability), along x	0.059	µm	0		0
Global scale factor (including traceability), along y	0.128	µm	0		0
Straightedge	0.155	µm	0		0
CMM Geometrical errors	0.058	µm	73.856	1/m	4.264
Reference system	0.913	µrad	1		0.913
				$u(y)$	**10.865**
	(k=2)			U	21.729

Angle of inclination of the torus axis on the plane yz	input uncertainty $u(x_i)$		Sensitivity c_i		Standard component $u_i(y)$ / µrad
Stylus tip radius	0.707	µm	0		0
Noise of the probing system	0.112	µm	5.727	1/m	0.643
Probing system anisotropy	0.071	µm	3.927		0.278
Global scale factor (including traceability), along x	0.023	µm	0		0
Global scale factor (including traceability), along y	1.443	µm	0		0
Straightedge	0.100	µm	0		0
CMM Geometrical errors	0.087	µm	4.534	1/m	0.393
Reference system	2.250	µrad	1		2.250
				$u(y)$	**2.389**
	(k=2)			U	4.778

The reported expanded uncertainty of measurement *U* is stated as the standard uncertainty of measurement multiplied by the coverage factor *k* = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%.
In the evaluation of the standard uncertainty, the long-term stability of the object under measurement has not been considered.

REFERENCES

[1] Gapinski B, Wieczorowski M 2014 Measurement of Diameter and Roundness on Incomplete Outline of Element with Three-Lobbing Deviation Procedia Engineering 69, 247 – 254

[2] EN ISO 17450-1 : Geometrical product specifications (GPS) -- General concepts -- Part 1: Model for geometrical specification and verification

[3] EN ISO 1:2016 Geometrical product specifications (GPS) – Standard reference temperature for the specification of geometrical and dimensional properties